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PHYSIOLOGY OF PROLONGED BED REST

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ABSTRACT

Rest in bed has been a normal procedure used by physicians for centuries in the treatment of injury and disease. Exposure of patients to prolonged bed rest (>24 hr) in the horizontal position induces adaptive deconditioning responses. Thus "healing" proceeds concomitantly with deconditioning. While deconditioning responses are appropriate for patients or test subjects in the horizontal position, they usually result in adverse physiological responses, such as fainting and muscular weakness, when the patients assume the upright posture. These deconditioning responses result from reduction in hydrostatic pressure within the cardiovascular system, virtual elimination of longitudinal pressure on the long bones, some decrease in total-body metabolism (exercise), changes in diet, and perhaps psychological impact from the different environment. Essentially every system in the body is affected by bed-rest deconditioning. An early stimulus is the cephalic shift of fluid from the legs which increases atrial pressure and induces compensatory responses for fluid and electrolyte redistribution. Without countermeasures, deterioration in strength and muscle function occurs within 1 wk while increased calcium loss may continue for months. In addition to problems with the cardiovascular, muscle and bone systems, increased research efforts should be focused on the effects of deconditioning on drug and carbohydrate metabolism, and the immune system.

KEYWORDS

Bed-rest deconditioning, remedial exercise training, fluid-electrolyte metabolism, hydrostatic pressure, carbohydrate metabolism.

INTRODUCTION

Prolonged bed rest has been used by physicians for centuries in treating illness and injury. Some infirmities may require rest for the patient, but the recumbent position may not be necessary. Other infirmities may have required that the

patient should not stand, but there was no reason to reduce or eliminate physical exercise. The deconditioning (acclimation) responses of healthy and sick or injured patients subjected to bed rest are caused by some combination of reduction of hydrostatic pressure within the cardiovascular system, greatly reduced pressure on the long bones, probable reduction in exercise metabolism, dietary changes, and probably changed psychological inputs from the different environment. Thus, early in bed rest, the healing process occurs simultaneously with the deconditioning syndrome. It is unknown whether deconditioning helps or hinders healing.

Asher (1947) has described vividly the major factors contributing to the deconditioning process: "Look at a patient lying long in bed, what a pathetic picture he makes! The blood clotting in his veins, the lime draining from his bones, the scybala stacking up in his colon, the flesh rotting from his seat, the urine leaking from his distended bladder, and the spirit evaporating from his soul!"

The mechanisms of this bed-rest deconditioning syndrome have only just begun to be studied in detail. The first step was to collate the signs, symptoms, and physiological changes and organize them into a time distribution, Table 1. From this table it is clear that fluid-electrolyte parameters are disturbed early in bed rest; muscle atrophy next (increased urine nitrogen and hydroxyproline; reduced lean body mass); and significant urine calcium loss and decreased bone density occur later.

FLUID-ELECTROLYTE SHIFTS

To simulate the physiological responses of astronauts during exposure to microgravity (weightlessness), the head-down posture (by 5°-6° from horizontal) has been adopted. With head-down bed rest the same changes occur as during horizontal bed rest, but they happen more quickly. Initially, when the body is moved from the sitting or standing position to the slightly head-down position, fluid shifts from the extremities (mainly thighs and legs) to the thorax and head resulting in various signs and symptoms, some inducing discomfort (Table 2). Most disappear by the fourth day. Fifteen minutes after head-down tilt this headward fluid shift increased stroke volume and central venous pressure (from 9 to 13 cm H_2O, $P < 0.05$) with no change in heart rate and a decrease in total peripheral resistance (Gaffney, 1985). Four hours after -5° head-down tilt the interstitial fluid pressures (measured with wick catheters) decreased from 4.6 to -2.8 mmHg ($P < 0.05$) in the anterior tibialis and from 0.6 to -3.8 mmHg ($P < 0.05$) in leg subcutaneous tissue (Hargens, 1983) suggesting tissue to vascular space fluid shifts. About 900 ml of fluid shifts from the two thighs and legs. Plasma volume increases by 11.5% after 30 min of tilt and then decreases by 125 ml (4%) at 6 hr, by 150-300 ml (5-10%) after 24 hr, by 350-450 ml (10-13%) on day 4, and can reach -30% at 180 days of bed rest (Donaldson, 1969; Gauquelin, 1985; Nixon, 1979; Volicer, 1976; Fig. 1). These plasma volume losses are not influenced by moderate isotonic or isometric exercise training during bed rest (Greenleaf, 1977b); but heavy isotonic training can maintain plasma volume at control levels during one month of -6° bed rest (Greenleaf, 1988). The decrease in body water during the first 24 hr of bed rest occurs via an osmotic diuresis ($\dot{V}$ = 2.5 ml/min) followed by a small increase in urine output (1.5 to 2.0 ml/min) during 7-14 days; voluntary fluid intake is unchanged (Greenleaf, 1977a). The initial stimulus for the diuresis appears to be the increase in central venous pressure that is associated

TABLE 1. Physiological changes during bed rest

0-3 Days	4-7 Days	8-14 Days	Over 15 days
Increases in:	Increases in:	Increases in:	Increases in:
Urine volume	Urine creatinine, hydroxyproline, phosphate, nitrogen, and potassium excretion	Urine pyrophosphate	Peak hypercalciuria
Urine Na^+, Cl^-, Ca^{2+} and osmol excretion	Plasma globulin, phosphate and glucose concentrations	Sweating sensitivity	Sensitivity to thermal stimuli
Plasma osmolality	Blood fibrinogen	Exercise hyperthermia	Auditory threshold (secondary)
Hematocrit	Fibrinolytic activity and clotting time	Exercise maximal heart rate	Decreases in:
Venous compliance	Focal point	Decreases in:	Bone density
Decreases in:	Hyperemia of eye conjunctiva and dilation of retinal arteries and veins	Red blood cell mass	
Total fluid intake	Auditory threshold	Leucocyte phagocytosis	
Extracellular (plasma, interstitial) and intracellular volumes	Decreases in:	Tissue heat conductance	
Calf blood flow	Near point of visual acuity	Lean body mass	
Resting heart rate	Orthostatic tolerance	Body fat content	
Secretion of gastric juice	Nitrogen balance		
Glucose tolerance			
Head-to-foot ($+G_z$) acceleration tolerance			

with moderate decreases in plasma aldosterone, renin activity, and vasopressin which return to normal after 24 hr (Nixon, 1979). The general consensus is that neither renal plasma flow, glomerular filtration rate, nor the functioning of the adrenergic nervous system (plasma catecholamines) are changed during bed rest (Chobanian, 1974; Fuller, 1970; Pequignot, 1985; Zager, 1974). Gharib (1985) reported a slight, transient increase in plasma atrial natriuretic factor during the first 30 min of -9° bed rest that would have been too short a response to account for the Na-osmotic diuresis on the first day of bed rest. Because cardiac transplant patients exhibit diuretic responses, although somewhat attenuated, to water immersion (Convertino, 1984), clearly redundant mechanisms that are not fully inderstood must be available to control fluid-electrolyte metabolism during bed rest.

TABLE 2. Time course of signs and symptoms causing discomfort in men during -6° head-down bed rest (Güell et al. 1984).

Symptomatology	Subjects	Beginning, hours	Maximum, hours	Disappearance, hours
Feeling of head fullness	3	2	12	24
Nasal congestion	3	4	24	96
Buccal and gingival turgescence	3	4-6	48	96
Facial oedema	3	24	48	72
Palpebral oedema	3	24	48	96
Headache	1	24	48	72
Dizziness	1	--	48	--

LEAN BODY MASS

Lean body mass (LBM) comprises everything in the body besides fat. Thus it involves mainly water, muscle, and bone. Regarding muscle, calf circumferences and lower leg volumes were decreased significantly by 3.3% and 4.5%, respectively, after 8 hr of -5° bed rest; but soleus muscle water content was unchanged while fluid continued to be lost from the anterior tibialis and overlying subcutaneous tissue (Hargens, 1983). These small decreases in muscle water content caused no significant change in plantar flexion isometric or isokinetic peak torque strengths. With an adequate diet (2,800-3,100 kcal/day), there are minimal changes in LBM. Total LBM decreases by about 0.8 kg after 14 days of horizontal bed rest without exercise training, by 1.1 kg with isometric training, and by 1.0 kg with isotonic training (Greenleaf, 1977a). Corresponding losses in body fat were 0.2 kg, 0.2 kg, and 0.7 kg, respectively. Thus, loss of body fat content is proportional to total metabolism while loss of LBM appears to be associated with the reduced hydrostatic pressure. Results from a more recent study indicated no significant changes in peak O_2 uptake, strength, and endurance in healthy men after 30 days of -6° bed rest with performance of daily, strenuous isokinetic and isotonic exercise training (Greenleaf, unpublished data). So reduced aerobic working capacity, muscular strength, and endurance are not inevitable consequences of exposure to prolonged bed rest. Body density was unchanged in the exercise group and also in the nonexercise group. So moderate activity (movement) during bed rest in healthy men without additional exercise training can essentially preserve muscular strength, but not aerobic capacity.

Nitrogen balance becomes negative for the first 60-90 days of bed rest and then returns to essentially zero (reaches equilibrium) after 182-252 days of bed rest; exercise during bed rest accentuates nitrogen loss (Bychkov, 1979, Donaldson, 1969).

Like aging, bed-rest deconditioning results in loss of bone mineral content (BMC) and total body calcium. The latter decreases by about 6.1 mg/day over 35 days of bed rest, and the decrease is reduced to 0.9-1.1 mg/day over 140 to 252 days of bed rest (Donaldson, 1970; Greenleaf, 1977a; LeBlanc, 1987; Lynch, 1967;

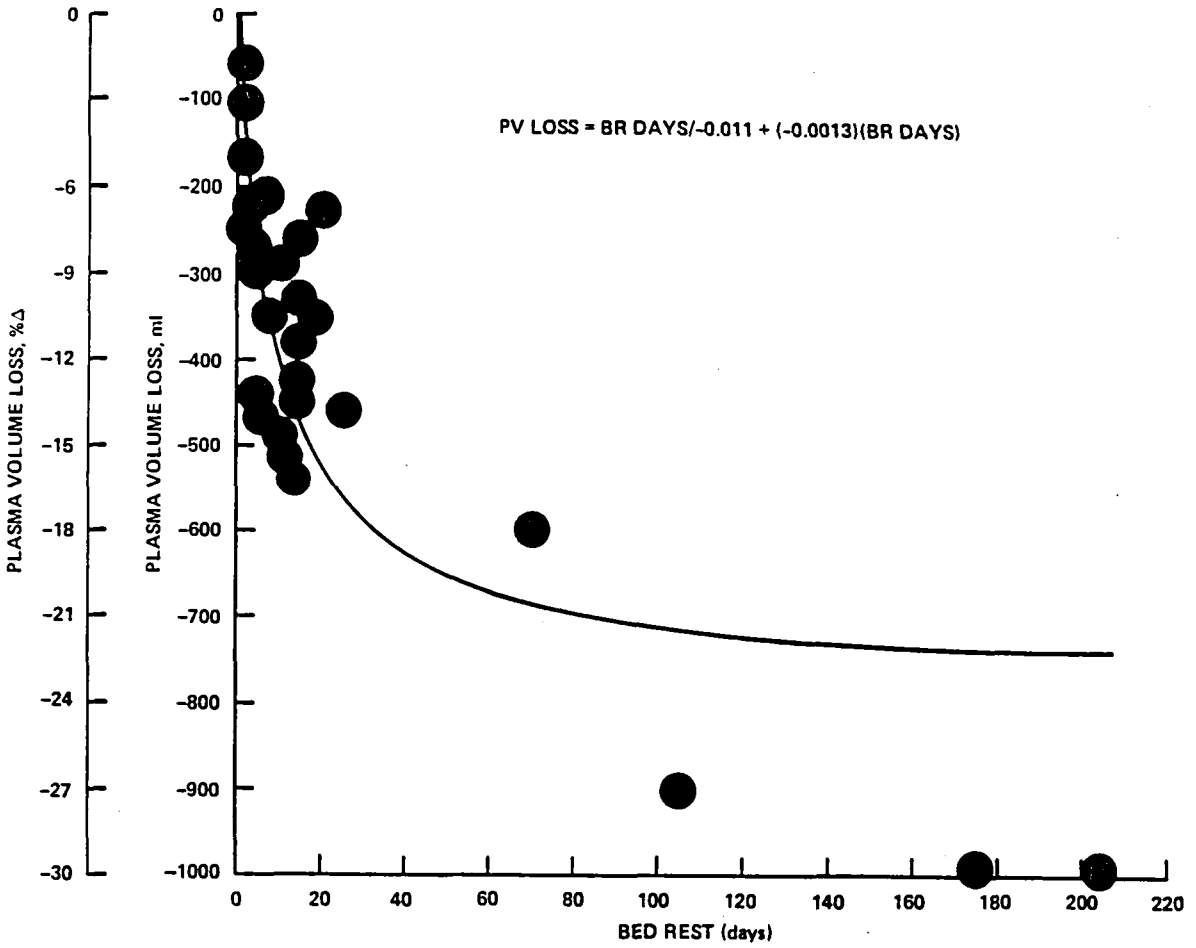

FIG. 1. Plasma volume loss during bed rest with data from studies that used no remedial procedures (from Greenleaf et al., 1977b, with permission).

Schneider, 1984; Whedon, 1949). The change appears to follow a logarithmic decay curve; the rate of Ca loss decreases as bed rest lengthens. Because vigorous exercise training during bed rest has no effect on the rate of urinary Ca loss (Greenleaf, 1977a; Rodahl, 1967), the hypercalciuria could be the result of reduced hydrostatic pressure; i.e., change in bone blood flow and/or to the large reduction in axial pressure on the skeleton. Whedon (1949) found that fluid shifting and axial loading in an oscillating bed ($+G_z$ to $-G_z$) during bed rest reduced hypercalciuria by 51%. Also, quiet standing for 3 hr/day during bed rest significantly reduces urinary Ca loss (Issekutz, 1966). Standing increases bone axial pressure and hydrostatic pressure. Thus, increasing axial pressure, perhaps by impact loading, would be a most appropriate remedial procedure to attenuate bed-rest-induced hypercalciuria.

The basic premise is that increased excretory Ca loss during bed rest will induce reduction in bone mineral content. Bone mineral content of the lumbar spine and radius is unchanged in nonexercised and exercise-trained men after 4 weeks of -6° bed rest (Arnaud, 1987), and in nonexercised men during 5 weeks of horizontal bed

rest (LeBlanc, 1987). Further, there is no change in iliac crest biopsy parameters (trabecular volume, mean cortical thickness, or mean trabecular plate thickness) in nonexercise or exercise-trained men after 120 days of -5° bed rest (Vico, 1987). Thus, the rather meager evidence suggests that bone mineral content (density) is not significantly reduced in healthy men over 4 months of bed rest.

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16. Abstract

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